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U.S. FISH & WILDLIFE SERVICE
REGION 6



CONTAMINANTS PROGRAM

CONTAMINANTS INFORMATION BULLETIN

Environmental Contaminants in Sediments
from
Oilfield Produced Water Discharge Points

By

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U.S. FISH AND WILDLIFE SERVICE
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INTRODUCTION

Oilfield produced water is generated from the extraction of oil mixed with groundwater. A separator is used to physically remove the water from the oil; however, the produced water can contain residual amounts of oil. Additionally, malfunction of the separator equipment can cause inefficient separation and result in higher amounts of oil in the water. The Wyoming Department of Environmental Quality (WY DEQ) regulates the discharge of produced waters under the National Pollution Discharge Elimination System (NPDES). WY DEQ permits 10 $\mu\text{g/l}$ of oil in produced water discharged into regulated waters of the state. Produced water discharges are not permitted into Class I waters (surface waters protected from degradation from point source discharges) and semi-annual bioassays are required for discharges into Class II waters (streams supporting game fish). Discharges into Class III (streams supporting a non-game fisheries) and Class IV (intermittent streams) waters only require annual water quality analyses. Lawrence et al. (1994) concluded that the criteria allowing 10 $\mu\text{g/l}$ of oil in produced water does not assure protection of aquatic communities.

The original objectives of the study were: 1). to determine if wastewater discharges are contributing potentially adverse concentrations of contaminants into wetlands providing important habitat for aquatic birds or threatened and endangered species; and 2). assess the practicability of using MICROTOX[®] and sediment pore water bioassay tests for screening potential contaminant problems. Given the limited amount of funding and staff, we focused primarily on oilfield produced water discharges as they have the most potential of all permitted discharges in Wyoming of contributing adverse concentrations of contaminants into wetlands. Limited staff and time prevented us from adequately pursuing the second objective.

STUDY AREA AND METHODS

Oilfield produced water discharges were selected for study if they had the following characteristics: presence of a visible oil sheen, tar-like deposits in the soil at the discharge area, and discharge into a wetland used by aquatic birds. Four general locations were the focus of this investigation (Figure 1).

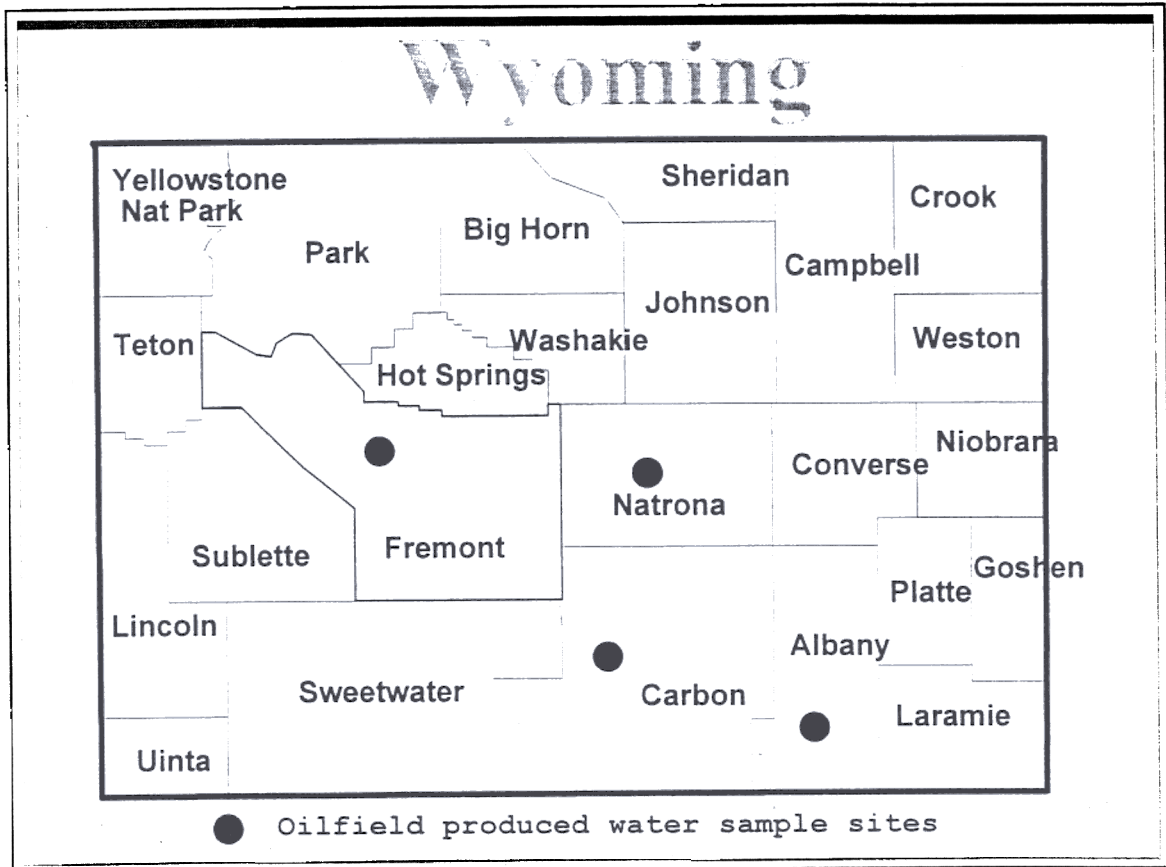


Figure 1. Location of oilfield produced water discharges sampled during study.

six discharge/wetland complexes were selected as sample sites within these four locations (Table 1).

Table 1. Distance (in meters) of wetlands receiving oilfield produced waters from the discharge pipe.

Site	Distance in meters
Pilot Butte - Fremont Co.	300
UNOCAL - Natrona Co.	500
Arnell - Natrona Co.	4
Mahoney - Carbon Co.	20
O'Brien - Carbon Co.	500
Little Laramie - Albany Co.	10

Four sediment samples were collected at each sample site at increasing distances from the discharge point. At each site, a sediment sample was collected from the receiving stream within three meters downstream of the discharge. Sediment samples were collected with a chemically-clean stainless-steel spoon, placed in chemically-clean glass jars with teflon-lined lids and frozen as soon as possible. Sediment samples were submitted to the Service's Patuxent Analytical Control Facility (PACF) or designated contract laboratories for trace element and hydrocarbon analyses. Trace element analysis included scans for: arsenic, mercury, and selenium using atomic absorption spectroscopy. Inductively Coupled Plasma Emission Spectroscopy was used to scan for a variety of elements including boron, barium, copper, lead, vanadium and zinc. Sediments from the Natrona and Carbon county sites were analyzed for trace elements. An extended scan for aromatic hydrocarbons was conducted on sediment samples from the sites in Albany, Carbon, Fremont and Natrona counties. Quality assurance and quality control was provided by PACF. Residues are expressed in $\mu\text{g/g}$ (ppm) dry weight unless otherwise specified.

RESULTS AND DISCUSSION

Trace Elements

Trace element concentrations in sediment samples are shown in Table 2. Sediments from a wetland receiving oilfield produced water from the Arnell oil production site were moderately polluted with nickel and heavily polluted with zinc. Sediments from a wetland receiving oilfield produced water from the Mahoney oil production site in Carbon County were heavily polluted with barium. Sediments from a wetland receiving oilfield produced water from the UNOCAL production site in Natrona County were moderately to heavily polluted with arsenic and barium.

Aliphatic Hydrocarbons

Differentiating petrogenic from biogenic compounds in the interpretation of hydrocarbon residues in sediments and biota is important. Petrogenic compounds have approximately equal proportions of odd- and even-numbered aliphatics (Hall and Coon 1988). Also, high ratios of pristane and phytane to nC17 and nC18, respectively, indicate recent or chronic exposure to petroleum compounds (Anderson et al. 1978, Farrington et al. 1973, Hall and Coon 1988). The Carbon Preference Index (CPI) is also used to differentiate between oiled and non-oiled matrices (Farrington and Tripp 1977). Sediments collected immediately downstream of the discharges at the Little Laramie and Pilot Butte had almost equal proportions of odd- and even-numbered aliphatics (Table 3) suggesting recent or chronic exposure to petroleum compounds. CPI values for sediments from the discharges at the Little Laramie and Pilot Butte ranged from 1.08 to 1.22. CPI values less than 3 indicate oiled sediments (Farrington and Tripp 1977). CPI values from ponds downstream from the discharges were greater than 3. Aliphatic hydrocarbon concentrations from sediments are shown in Table 4.

Aromatic Hydrocarbons

PAH's detected in the sediments from the UNOCAL site included benzo(a)pyrene, benzo(b)fluoranthene, chrysene, and indeno(1,2,3-cd)pyrene (Table 5). Benzo(a)pyrene and chrysene have been shown to induce embryotoxicity in mallards (*Anas platyrhynchos*). Based on topical applications to eggs, $0.036 \times 10^{-3} \mu\text{g}$ benzo(a)pyrene/g and $0.273 \times 10^{-3} \mu\text{g}$ chrysene/g caused deformities, growth reductions, and mortality (Hoffman and Gay 1981, as cited in Eisler 1987). In doses of 2.0 mg/kg/egg, benzo(a)pyrene and indeno(1,2,3-cd)pyrene severely decreased survival while chrysene caused a significant increase in lesions in embryos from common eider and domestic chicken, turkey, and duck (Brunstrom et al., 1990). Levels of the PAH's (benzo(a)pyrene, benzo(b)fluoranthene, chrysene, and indeno(1,2,3-cd)pyrene) were lower in sediments from the UNOCAL discharge than in the sediments from the downstream marsh and pond receiving the effluent. Total hydrocarbons in sediments were higher at the discharge than in the wetland and lower in the pond than in the marsh. At the Albany and Fremont county sites total hydrocarbons and oil and grease were also higher in sediments from the discharge outfalls than in the receiving wetlands. Sediment samples from all sites had high concentrations of oil and grease (Table 6).

SUMMARY

The limited number of sediment samples at produced water discharge outfalls show high concentrations of PAH's; however, concentrations are lower in the receiving wetlands. The Little Laramie and Pilot Butte discharges had the highest concentrations of aliphatics, aromatics and unresolved complex mixtures. Unresolved complex

mixture concentrations are characteristic of petrogenic compounds. Elevated trace elements found in the sediments included arsenic, barium, nickel and zinc. These elements, especially barium, are typically associated with oilfield produced water discharges. Additional research should be conducted to determine the chronic effects of oilfield produced water discharges on aquatic birds. The current water quality criteria of 10 $\mu\text{g/l}$ of oil and grease may not be adequate to protect wildlife from the chronic effects of hydrocarbons associated with the discharges. Sediments at the receiving wetlands at the Arnell and UNOCAL sites released a visible sheen when agitated, indicating that they are acting as a sink for petroleum hydrocarbons. Additionally, soils at the UNOCAL discharge point were stained with tar-like deposits. A visible sheen on the water surface could pose a hazard to breeding aquatic birds. Aquatic birds contacting the oily sheen can pick up petroleum hydrocarbons on their belly feathers and ultimately transfer the oil to their eggs when they return to their nest to incubate (King and Le Fever 1979). Studies have shown that as little as 5 μl of oil on the egg shell can cause embryo mortality (Leepen 1976, Szaro 1979).

One promising technique for removing or reducing contaminants from oilfield produced waters involves using constructed wetlands as filters. Marathon Oil and the Colorado School of Mines have developed a pilot project at the Pitchfork oilfield near Meeteetse, Wyoming (Colorado School of Mines 1991). The Pitchfork Pilot Project has shown promising results in reducing hydrocarbons.

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Table 2. Trace element concentrations (in $\mu\text{g/g}$ dry weight) in sediment from four oilfield produced water discharges in Natrona and Carbon counties, Wyoming (*=moderately polluted; **=heavily polluted)

Trace Element	Arnell - Poison Spider	Mahoney Discharge- Carbon Co.	O'Brien Discharge- Carbon Co.	UNOCAL Discharge - Marsh	UNOCAL Discharge	UNOCAL Discharge - Pond	UNOCAL Discharge - Pond
Al	2450	855	1370	4280	5150	5430	4340
As	2.81	2.24	<0.4604	*4.08	*4.38	*7.55	*5.71
B	<4.7985	<4.7081	<4.6041	5.95	<4.7801	5.83	<4.9505
Ba	21.8	**223	*57.5	*33.3	*22.3	**73.7	**76.2
Be	0.273	<0.1883	<0.1842	0.708	0.479	0.651	0.811
Cd	0.217	<0.1883	<0.1842	0.284	<0.1912	<0.1912	<0.1980
Cr	5.26	<4.7081	<4.6041	7.14	5.62	5.41	<4.9505
Cu	<4.7985	<4.7081	<4.6041	15.6	14.1	5.66	6.09
Fe	5070	2070	1490	7600	3080	6930	7530
Hg	<0.0960	<0.0942	<0.0921	<0.0954	<0.0956	<0.0956	<0.0990
Mg	1390	1080	550	1390	1410	2810	2890
Mn	110	53	12	35	28	138	132
Mo	<4.7985	<4.7081	<4.6041	6.09	<4.7801	<4.7801	<4.9505
Ni	*24.6	<4.7081	<4.6041	14.2	10.7	4.89	6.79
Pb	<4.7985	<4.7081	<4.6041	21.2	<4.7801	6.62	13.5
Se	0.65	4.49	<0.4604	1.03	0.54	1.29	1.01
Sr	165	561	29.8	52.1	36.5	1190	936
V	106	<4.7081	<4.6041	34.1	31.5	6.64	<4.9505
Zn	**605	50.2	8.46	53.8	26	28.7	33.7

Table 3. Aliphatic hydrocarbon ratios and carbon preference indices for sediments collected from sites receiving oilfield produced waters in Wyoming

Site	Sample Id	Odd/Even Ratio	Pristane/n-C17 Ratio	Phytane/n-C18 Ratio	Pristane/Phytane Ratio	Carbon Preference Index
Little Laramie Discharge	HEINSD02	1.14	1.02	2.74	0.56	1.08
Little Laramie Discharge	HEINSD03	1.18	0.89	2.35	0.56	1.16
Little Laramie Discharge	HEINSD04	1.36	1.00	3.06	0.55	1.17
Pilot Butte Discharge	PIOFSD01	0.97	2.18	6.06	0.51	1.10
Pilot Butte Discharge	PIOFSD02	1.13	0.78	3.09	0.51	1.22
Pond - Pilot Butte Discharge	PIPOSD01	6.32	0.06	6.79	0.06	11.04
Pond - Pilot Butte Discharge	PIPOSD02	4.68	0.21	9.47	0.12	9.50
Pond - Pilot Butte Discharge	PIPOSD03	5.58	0.23	10.62	0.14	10.39
Pond - UNOCAL Discharge	PSPOSD03	2.69	0.34	4.25	0.31	6.50
Pond - UNOCAL Discharge	PSPOSD04	4.35	0.50	21.07	0.14	6.12

Table 4. Aliphatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

COMPOUND	Little Laramie Sample 1	Little Laramie Sample 2	Little Laramie Sample 3
n-decane	4.685553	2.948371	7.666308
n-dodecane	4.037551	3.463371	7.190878
n-tetradecane	19.988369	11.88361	31.801805
n-hexadecane	21.965606	12.334235	27.834937
n-octadecane	21.350835	12.21836	25.502359
n-eicosane	15.601894	10.563924	22.256064
n-docosane	17.844978	8.03399	21.817777
n-tetracosane	15.169893	6.630617	12.168035
n-hexacosane	8.357564	3.991245	6.953163
n-octacosane	2.176622	1.686623	6.113732
n-triacontane	12.644347	5.214368	11.447461
n-dotriacontane	6.48002	3.180121	6.537162
n-tetratriacontane	2.542162	5.040556	1.916577
TOTAL EVEN # PAH's	152.85	87.19	189.21
n-undecane	4.18709	4.203682	7.33945
n-tridecane	6.945252	3.72087	14.872042
n-pentadecane	42.203207	28.576027	94.647699
n-heptadecane	31.835175	17.876915	42.818408
n-nonadecane	20.719448	10.512424	24.432641
n-heneicosane	18.12744	8.845114	19.908628
n-tricosane	20.270832	12.656109	19.878914
n-pentacosane	8.77295	5.220806	8.966311
n-heptacosane	4.735399	2.497747	6.737734
n-nonacosane	7.809255	3.810995	7.644022
n-hentriacontane	5.71571	3.167246	5.779445
n-tritriacontane	2.974163	1.808935	4.754299
TOTAL ODD # PAH's	174.30	102.90	257.78
phytane	58.602642	28.717652	77.992794
pristane	32.549639	15.958543	42.91498

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Table 4 (Continued). Aliphatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

	Pilot Butte Discharge Sample 1	Pilot Butte Discharge Sample 2
COMPOUND		
n-decane	<.411684	0.843122
n-dodecane	<.411684	1.594028
n-tetradecane	5.219063	6.639587
n-hexadecane	9.418549	8.194094
n-octadecane	11.737668	17.626523
n-eicosane	28.681863	31.81908
n-docosane	28.715292	28.363157
n-tetracosane	19.142135	22.869689
n-hexacosane	12.055241	15.04007
n-octacosane	8.603723	12.888352
n-triacontane	12.046884	12.528269
n-dotriacontane	8.741617	9.766165
n-tetratriacontane	16.877337	14.79416
TOTAL EVEN # PAH's	161.24	182.97
n-undecane	0.559931	1.154902
n-tridecane	1.516829	2.555714
n-pentadecane	16.660051	23.932375
n-heptadecane	16.797944	35.380393
n-nonadecane	17.031945	22.935558
n-heneicosane	29.191651	29.272148
n-tricosane	21.381861	27.252168
n-pentacosane	18.323131	19.66846
n-heptacosane	9.301548	12.594138
n-nonacosane	8.716545	12.141838
n-hentriacontane	8.837724	11.263585
n-tritriacontane	7.295823	8.883522
TOTAL ODD # PAH's	155.61	207.03
phytane	71.16144	54.51751
pristane	36.637904	27.550774

Table 4 (Continued). Aliphatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

	Pilot Butte	Pilot Butte	Pilot Butte
	Pond	Pond	Pond
COMPOUND	Sample 1	Sample 2	Sample 3
n-decane	0.02289	0.025536	<.023481
n-dodecane	<.021756	<.022333	<.023481
n-tetradecane	<.021756	<.022333	<.023481
n-hexadecane	<.021756	0.049728	0.046905
n-octadecane	0.02507	0.066976	0.07381
n-eicosane	0.035534	0.041664	0.05381
n-docosane	0.0327	0.062272	0.083095
n-tetracosane	0.03597	0.078624	0.100714
n-hexacosane	0.061911	0.11536	0.16619
n-octacosane	0.100061	0.114912	0.101667
n-triacontane	0.077389	0.096544	0.112143
n-dotriacontane	0.026814	0.061376	0.071429
n-tetratriacontane	0.024416	0.103712	0.102143
TOTAL EVEN # PAH's	0.44	0.82	0.91
n-undecane	<.021756	<.022333	<.023481
n-tridecane	<.021756	<.022333	<.023481
n-pentadecane	0.027904	0.065856	0.080476
n-heptadecane	0.159356	0.376767	0.487619
n-nonadecane	0.028122	0.054208	0.085952
n-heneicosane	0.085891	0.144032	0.186905
n-tricosane	0.271189	0.471518	0.742619
n-pentacosane	0.321765	0.512286	0.801429
n-heptacosane	0.571591	0.718814	1.010238
n-nonacosane	0.750131	0.833277	0.964762
n-hentriacontane	0.451474	0.525726	0.58381
n-tritriacontane	0.131671	0.115808	0.141429
TOTAL ODD # PAH's	2.80	3.82	5.09
phytane	0.170256	0.634366	0.784048
pristane	<.021756	0.07728	0.110476

Table 4 (Continued). Aliphatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

	UNOCAL	UNOCAL
	Pond	Pond
COMPOUND	Sample 1	Sample 2
n-decane	<.024631	<.023275
n-dodecane	<.024631	<.023275
n-tetradecane	0.0385	<.023275
n-hexadecane	0.044	<.023275
n-octadecane	0.10325	0.038008
n-eicosane	0.13375	<.023275
n-docosane	0.1355	0.157661
n-tetracosane	0.129	0.058419
n-hexacosane	0.1015	0.072965
n-octacosane	0.1345	0.139831
n-triacontane	0.16775	0.249161
n-dotriacontane	0.103	0.107688
n-tetratriacontane	0.51	0.065927
TOTAL EVEN # PAH's	1.60	0.89
n-undecane	<.024631	<.023275
n-tridecane	<.024631	<.023275
n-pentadecane	0.243	0.085869
n-heptadecane	0.40675	0.219131
n-nonadecane	0.137	0.081177
n-heneicosane	0.2985	0.189334
n-tricosane	0.59275	0.593107
n-pentacosane	0.435	0.304296
n-heptacosane	0.60575	0.516153
n-nonacosane	0.707	0.897168
n-hentriacontane	0.637	0.778218
n-tritriacontane	0.2395	0.209042
TOTAL ODD # PAH's	4.30	3.87
phytane	0.43875	0.800976
pristane	0.138	0.1098

Table 5. Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Compound/Site Name	Sample ID PSUNMAR1	PSUNWET3	PSPOSD03
	UNOCAL Marsh	UNOCAL Pond	UNOCAL Pond
1,2,5,6-dibenzanthracene	0.028309	<.158452	<.024631
1,2-benzanthracene	0.07431	<.158452	<.024631
1,6,7-Trimethyl-naphthalene	0.955414	1.214364	<.024631
acenaphthalene	<.023749	<.158452	<.024631
acenaphthene	0.046001	<.158452	<.024631
anthracene	0.02477	<.158452	<.024631
benzo(a)pyrene	0.046001	<.158452	<.024631
benzo(b)fluoranthene	0.063694	<.158452	<.024631
benzo(e)pyrene	0.09908	<.158452	<.024631
benzo(g,h,i)perylene	0.042463	<.158452	<.024631
benzo(k)fluoranthene	0.063694	<.158452	<.024631
biphenyl	0.081387	<.158452	<.024631
C1-chrysenes	0.803255	<.158452	0.0756
C1-dibenzothiophenes	1.2385	0.389254	0.069575
C1-Fluoranthenes & Pyrenes	0.778485	<.158452	0.037
C1-fluorenes	0.360934	0.263158	0.02725
C1-naphthalenes	1.376504	1.260965	<.024631
C1-Phenanthrenes & Anthracenes	0.509554	0.375548	0.044725
C2-chrysenes	1.698514	0.175439	0.13
C2-dibenzothiophenes	4.501062	0.858004	0.16185
C2-fluorenes	0.912951	0.638706	0.0558
C2-naphthalenes	2.402689	3.179825	0.051825
C2-Phenanthrenes & Anthracenes	1.493277	0.638706	0.11975
C3-chrysenes	0.555556	<.158452	0.040925
C3-dibenzothiophenes	8.683652	1.091009	0.23445
C3-fluorenes	2.508846	0.838816	0.138925
C3-naphthalenes	3.673036	5.076754	0.08695
C3-Phenanthrenes & Anthracenes	2.760085	0.550987	0.16955
C4-chrysenes	0.721868	<.158452	0.0438
C4-naphthalenes	3.085633	3.86239	0.126325
C4-Phenanthrenes & Anthracenes	2.664544	0.348136	0.15345
chrysene	0.491861	<.158452	0.03995
dibenzothiophene	0.19816	<.158452	<.024631
fluoranthene	0.042463	<.158452	<.024631
fluorene	0.109696	<.158452	<.024631
indeno(1,2,3-cd)pyrene	0.031847	<.158452	<.024631
naphthalene	0.307856	<.158452	<.024631
perylene	0.102619	<.158452	<.024631
phenanthrene	0.184006	<.158452	<.024631
pyrene	0.215853	<.158452	<.024631

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Table 5 (Continued). Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Compound/Site Name	Sample ID PSUNMAR1 UNOCAL Marsh	PSUNWET3 UNOCAL Pond	PSPOSD03 UNOCAL Pond
unresolved complex mixture			273.75
1-methylnaphthalene	NA	NA	<.024631
1-methylphenanthrene	NA	NA	<.024631
2,6-dimethylnaphthalene	NA	NA	<.024631
2-methylnaphthalene	NA	NA	<.024631
Total PAH's	43.94	20.76	1.81

Table 5 (Continued). Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Compound/Site Name	Sample ID PSOSD04 UNOCAL Pond	HEINSD02 Little Laramie	HEINSD03 Little Laramie
1,2,5,6-dibenzanthracene	<.023275	<1.658227	<.641824
1,2-benzanthracene	0.028342	<1.658227	<.641824
1,6,7-Trimethyl-naphthalene	<.023275	4.348343	1.74456
acenaphthalene	<.023275	<1.658227	<.641824
acenaphthene	<.023275	<1.658227	<.641824
anthracene	<.023275	<1.658227	<.641824
benzo(a)pyrene	<.023275	<1.658227	<.641824
benzo(b)fluoranthene	<.023275	<1.658227	<.641824
benzo(e)pyrene	<.023275	<1.658227	<.641824
benzo(g,h,i)perylene	<.023275	<1.658227	<.641824
benzo(k)fluoranthene	<.023275	<1.658227	<.641824
biphenyl	<.023275	<1.658227	<.641824
C1-chrysenes	0.055768	3.491485	1.565501
C1-dibenzothiophenes	0.060249	26.60231	9.248487
C1-Fluoranthenes & Pyrenes	0.038383	2.650411	0.808034
C1-fluorenes	<.023275	2.124865	0.809643
C1-naphthalenes	<.023275	<1.658227	<.641824
C1-Phenanthrenes & Anthracenes	0.029374	10.80535	4.070072
C2-chrysenes	0.09631	7.189582	2.630456
C2-dibenzothiophenes	0.258124	44.305807	14.86124
C2-fluorenes	0.080801	5.170641	2.324739
C2-naphthalenes	<.023275	4.073939	1.975634
C2-Phenanthrenes & Anthracenes	0.133613	22.312786	7.422621
C3-chrysenes	0.026981	1.956135	0.960216
C3-dibenzothiophenes	0.396476	47.946	16.509882
C3-fluorenes	0.150506	13.926477	4.964916
C3-naphthalenes	0.029092	21.273241	8.373278
C3-Phenanthrenes & Anthracenes	0.203857	26.929052	9.750998
C4-chrysenes	0.030664	2.243832	1.222512
C4-naphthalenes	0.106773	31.753012	11.624855
C4-Phenanthrenes & Anthracenes	0.206931	18.985545	6.818785
chrysene	0.024259	2.332226	0.984421
dibenzothiophene	<.023275	16.115727	5.491889
fluoranthene	<.023275	<1.658227	<.641824
fluorene	<.023275	<1.658227	<.641824
indeno(1,2,3-cd)pyrene	<.023275	<1.658227	<.641824
naphthalene	<.023275	<1.658227	<.641824
perylene	<.023275	<1.658227	<.641824
phenanthrene	<.023275	5.149705	1.902279
pyrene	<.023275	<1.658227	<.641824

Table 5 (Continued). Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Compound/Site Name	Sample ID	PSPOSD04 UNOCAL Pond	HEINSD02 Little Laramie	HEINSD03 Little Laramie
unresolved complex mixture	452.57256	1326.74254	691.70851	
1-methylnaphthalene	<.023275	<1.658227	<.641824	
1-methylphenanthrene	<.023275	4.238265	1.583462	
2,6-dimethylnaphthalene	<.023275	<1.658227	<.641824	
2-methylnaphthalene	<.023275	<1.658227	<.641824	
Total PAH's	1.96	321.69	116.07	

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Table 5 (Continued). Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Compound/Site Name	Sample ID	HEINSD04 Little Laramie	PIOFSD01 Pilot Butte Discharge
1,2,5,6-dibenzanthracene		<.732603	<.411684
1,2-benzanthracene		<.732603	<.411684
1,6,7-Trimethyl-naphthalene		2.840025	5.507469
acenaphthalene		<.732603	<.411684
acenaphthene		<.732603	<.411684
anthracene		<.732603	<.411684
benzo(a)pyrene		<.732603	<.411684
benzo(b)fluoranthene		<.732603	<.411684
benzo(e)pyrene		<.732603	<.411684
benzo(g,h,i)perylene		<.732603	<.411684
benzo(k)fluoranthene		<.732603	<.411684
biphenyl		<.732603	<.411684
C1-chrysenes		1.922445	2.02106
C1-dibenzothiophenes		14.583074	9.937405
C1-Fluoranthenes & Pyrenes		0.945255	1.414579
C1-fluorenes		1.892973	3.731212
C1-naphthalenes		<.732603	5.890249
C1-Phenanthrenes & Anthracenes		6.308784	8.086142
C2-chrysenes		5.024403	3.534902
C2-dibenzothiophenes		25.103844	20.424336
C2-fluorenes		5.049248	7.903934
C2-naphthalenes		2.662445	12.053507
C2-Phenanthrenes & Anthracenes		11.951562	14.498005
C3-chrysenes		1.963414	1.097528
C3-dibenzothiophenes		23.906946	19.835196
C3-fluorenes		10.740363	13.374151
C3-naphthalenes		13.545147	25.298414
C3-Phenanthrenes & Anthracenes		14.06308	14.835238
C4-chrysenes		1.587267	0.956146
C4-naphthalenes		19.065594	24.436078
C4-Phenanthrenes & Anthracenes		10.702288	7.567223
chrysene		1.576347	1.044418
dibenzothiophene		9.3312	2.908489
fluoranthene		<.732603	<.411684
fluorene		<.732603	0.948457
indeno(1,2,3-cd)pyrene		<.732603	<.411684
naphthalene		<.732603	1.11629
perylene		<.732603	<.411684
phenanthrene		2.936422	2.01592
pyrene		<.732603	0.42208

Table 5 (Continued). Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Compound/Site Name	Sample ID	HEINSD04	PIOFSD01
		Little Laramie	Pilot Butte Discharge
unresolved complex mixture	1427.03265	1427.03265	760.086079
1-methylnaphthalene	<.732603	<.732603	3.163801
1-methylphenanthrene	1.681313	1.681313	2.915488
2,6-dimethylnaphthalene	<.732603	<.732603	3.886906
2-methylnaphthalene	<.732603	<.732603	2.726448
Total PAH's		187.70	210.86

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Table 5 (Continued). Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Sample ID	PIOFSD02	PIPOSD01
Compound/Site Name	Pilot Butte Discharge	Pilot Butte Pond
1,2,5,6-dibenzanthracene	<.435641	<.021756
1,2-benzanthracene	<.435641	<.021756
1,6,7-Trimethyl-naphthalene	2.98182	<.021756
acenaphthalene	<.435641	<.021756
acenaphthene	<.435641	<.021756
anthracene	<.435641	<.021756
benzo(a)pyrene	<.435641	<.021756
benzo(b)fluoranthene	<.435641	<.021756
benzo(e)pyrene	<.435641	<.021756
benzo(g,h,i)perylene	<.435641	<.021756
benzo(k)fluoranthene	<.435641	<.021756
biphenyl	<.435641	<.021756
C1-chrysenes	1.635042	<.021756
C1-dibenzothiophenes	8.562016	<.021756
C1-Fluoranthenes & Pyrenes	1.121682	<.021756
C1-fluorenes	1.998331	<.021756
C1-naphthalenes	3.58384	<.021756
C1-Phenanthrenes & Anthracenes	6.72772	<.021756
C2-chrysenes	2.775299	<.021756
C2-dibenzothiophenes	16.967768	0.045583
C2-fluorenes	4.700011	<.021756
C2-naphthalenes	7.250302	<.021756
C2-Phenanthrenes & Anthracenes	11.998243	0.046913
C3-chrysenes	0.76296	<.021756
C3-dibenzothiophenes	12.553782	0.050597
C3-fluorenes	7.832386	<.021756
C3-naphthalenes	15.774619	<.021756
C3-Phenanthrenes & Anthracenes	12.120518	0.035948
C4-chrysenes	0.627753	<.021756
C4-naphthalenes	15.347722	<.021756
C4-Phenanthrenes & Anthracenes	6.642332	0.027315
chrysene	0.756175	<.021756
dibenzothiophene	2.576375	<.021756
fluoranthene	<.435641	<.021756
fluorene	0.529652	<.021756
indeno(1,2,3-cd)pyrene	<.435641	<.021756
naphthalene	0.641563	<.021756
perylene	<.435641	<.021756
phenanthrene	1.721989	<.021756
pyrene	<.435641	<.021756

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Table 5 (Continued). Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Sample ID	PIOFSD02	PIPOSD01
Compound/Site Name	Pilot Butte Discharge	Pilot Butte Pond
unresolved complex mixture	577.011747	114.884897
1-methylnaphthalene	2.014711	<.021756
1-methylphenanthrene	2.123768	<.021756
2,6-dimethylnaphthalene	2.025338	<.021756
2-methylnaphthalene	1.569129	<.021756
Total PAH's	148.19	0.21

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Table 5 (Continued). Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Sample ID	PIPOSD02	PIPOSD03
	Pilot Butte	Pilot Butte
Compound/Site Name	Pond	Pond
1,2,5,6-dibenzanthracene	<.022333	<.023481
1,2-benzanthracene	<.022333	<.023481
1,6,7-Trimethyl-naphthalene	<.022333	<.023481
acenaphthalene	<.022333	<.023481
acenaphthene	<.022333	<.023481
anthracene	<.022333	<.023481
benzo(a)pyrene	<.022333	<.023481
benzo(b)fluoranthene	<.022333	<.023481
benzo(e)pyrene	<.022333	<.023481
benzo(g,h,i)perylene	<.022333	<.023481
benzo(k)fluoranthene	<.022333	<.023481
biphenyl	<.022333	<.023481
C1-chrysenes	<.022333	<.023481
C1-dibenzothiophenes	<.022333	<.023481
C1-Fluoranthenes & Pyrenes	<.022333	<.023481
C1-fluorenes	<.022333	<.023481
C1-naphthalenes	<.022333	0.023786
C1-Phenanthrenes & Anthracenes	<.022333	<.023481
C2-chrysenes	<.022333	<.023481
C2-dibenzothiophenes	0.029299	0.0285
C2-fluorenes	<.022333	<.023481
C2-naphthalenes	<.022333	0.029405
C2-Phenanthrenes & Anthracenes	0.046547	0.056738
C3-chrysenes	<.022333	<.023481
C3-dibenzothiophenes	0.029322	0.041119
C3-fluorenes	<.022333	<.023481
C3-naphthalenes	0.029322	0.037548
C3-Phenanthrenes & Anthracenes	<.022333	0.04631
C4-chrysenes	<.022333	<.023481
C4-naphthalenes	<.022333	0.036167
C4-Phenanthrenes & Anthracenes	<.022333	0.041452
chrysene	<.022333	<.023481
dibenzothiophene	<.022333	<.023481
fluoranthene	<.022333	<.023481
fluorene	<.022333	<.023481
indeno(1,2,3-cd)pyrene	<.022333	<.023481
naphthalene	<.022333	<.023481
perylene	<.022333	<.023481
phenanthrene	<.022333	<.023481
pyrene	<.022333	<.023481
unresolved complex mixture	94.975696	113.571429
Total PAH's	0.13	0.34

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Table 5 (Continued). Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Sample ID	ARNELL01	ARNELL02	MAHONEY1
	Arnell	Arnell	Mahoney
Compound/Site Name	Pond	Pond	Discharge
1,2,5,6-dibenzanthracene	0.235525	0.264045	0.040268
1,2-benzanthracene	0.412169	0.505618	0.110067
1,6,7-Trimethyl-naphthalene	26.614328	26.620787	4.950336
acenaphthalene	0.188911	0.219101	0.018792
acenaphthene	0.338567	0.511236	0.061745
anthracene	1.984789	0.963483	0.122148
benzo(a)pyrene	0.240432	0.132022	0.028188
benzo(b)fluoranthene	0.394995	0.55618	0.020134
benzo(e)pyrene	1.062316	1.095506	0.167785
benzo(g,h,i)perylene	0.277233	0.196629	0.034899
benzo(k)fluoranthene	0.394995	0.55618	0.020134
biphenyl	0.718842	0.446629	0.252349
C1-chrysenes	7.622669	8.601124	1.620134
C1-dibenzothiophenes	143.868989	114.376404	14.519463
C1-Fluoranthenes & Pyrenes	0.576546	10.69382	1.171812
C1-fluorenes	21.135918	14.91573	2.404027
C1-naphthalenes	0.613346	0.367978	1.056376
C1-Phenanthrenes & Anthracenes	38.476447	28.974719	7.297987
C2-chrysenes	17.058391	19.69382	2.828188
C2-dibenzothiophenes	308.478901	248.907303	30.348993
C2-fluorenes	65.176644	47.078652	6.916779
C2-naphthalenes	12.151619	10.817416	4.393289
C2-Phenanthrenes & Anthracenes	78.670265	67.109551	11.288591
C3-chrysenes	6.062316	5.269663	0.491275
C3-dibenzothiophenes	307.04367	253.280899	28.151678
C3-fluorenes	113.334151	85.679775	12.468456
C3-naphthalenes	77.725711	57.367978	8.77047
C3-Phenanthrenes & Anthracenes	103.093719	86.800562	9.844295
C4-chrysenes	5.581452	6.671348	1.085906
C4-naphthalenes	92.556428	66.117978	5.512752
C4-Phenanthrenes & Anthracenes	50.542198	50.688202	3.932886
chrysene	4.590285	4.747191	0.730201
dibenzothiophene	23.042198	17.073034	3.406711
fluoranthene	0.480864	0.393258	0.041611
fluorene	3.662905	1.688202	0.408054
indeno(1,2,3-cd)pyrene	0.110402	0.188202	<.008796
naphthalene	1.923454	1.876404	0.185235
perylene	0.444063	0.511236	0.01745
phenanthrene	7.119725	4.921348	1.692617
pyrene	0.905299	0.719101	0.185235
Total PAH's	1524.91	1247.60	166.60

Table 5 (Continued). Aromatic hydrocarbon compounds (in $\mu\text{g/g}$ dry weight) in sediment from oilfield produced water discharges in Albany, Carbon, Fremont and Natrona counties, Wyoming.

Sample ID OBRIEN01	
Compound/Site Name	O'Brien Discharge
1,2,5,6-dibenzanthracene	<.009577
1,2-benzanthracene	<.009577
1,6,7-Trimethyl-naphthalene	0.034759
acenaphthalene	<.009577
acenaphthene	<.009577
anthracene	<.009577
benzo(a)pyrene	<.009577
benzo(b)fluoranthene	<.009577
benzo(e)pyrene	<.009577
benzo(g,h,i)perylene	<.009577
benzo(k)fluoranthene	<.009577
biphenyl	<.009577
C1-chrysenes	0.013369
C1-dibenzothiophenes	0.13369
C1-Fluoranthenes & Pyrenes	0.012032
C1-fluorenes	0.018717
C1-naphthalenes	<.009577
C1-Phenanthrenes & Anthracenes	0.064171
C2-chrysenes	0.02139
C2-dibenzothiophenes	0.284759
C2-fluorenes	0.053476
C2-naphthalenes	0.046791
C2-Phenanthrenes & Anthracenes	0.102941
C3-chrysenes	<.009577
C3-dibenzothiophenes	0.251337
C3-fluorenes	0.09893
C3-naphthalenes	0.084225
C3-Phenanthrenes & Anthracenes	0.093583
C4-chrysenes	<.009577
C4-naphthalenes	0.064171
C4-Phenanthrenes & Anthracenes	0.044118
chrysene	<.009577
dibenzothiophene	0.030749
fluoranthene	<.009577
fluorene	<.009577
indeno(1,2,3-cd)pyrene	<.009577
naphthalene	<.009577
perylene	<.009577
phenanthrene	0.014706
pyrene	<.009577
Total PAH's	1.47

Table 6. Oil and grease concentrations (in $\mu\text{g/g}$ dry weight) in sediments from sites receiving oilfield produced water, Wyoming.

Sample ID	Site	County	Oil/Grease
HEINSD02	Little Laramie Discharge	Albany	196,364.21
HEINSD03	Little Laramie Discharge	Albany	86,574.13
HEINSD04	Little Laramie Discharge	Albany	93,079.45
PIOFSD01	Pilot Butte Discharge	Fremont	54,197.29
PIOFSD02	Pilot Butte Discharge	Fremont	54,375.94
PIPOSD01	Pond - Pilot Butte Discharge	Fremont	684.24
PIPOSD02	Pond - Pilot Butte Discharge	Fremont	571.72
PIPOSD03	Pond - Pilot Butte Discharge	Fremont	673.31
PSPOSD03	Pond - UNOCAL Discharge	Natrona	3,433.50
PSPOSD04	Pond - UNOCAL Discharge	Natrona	6,954.08